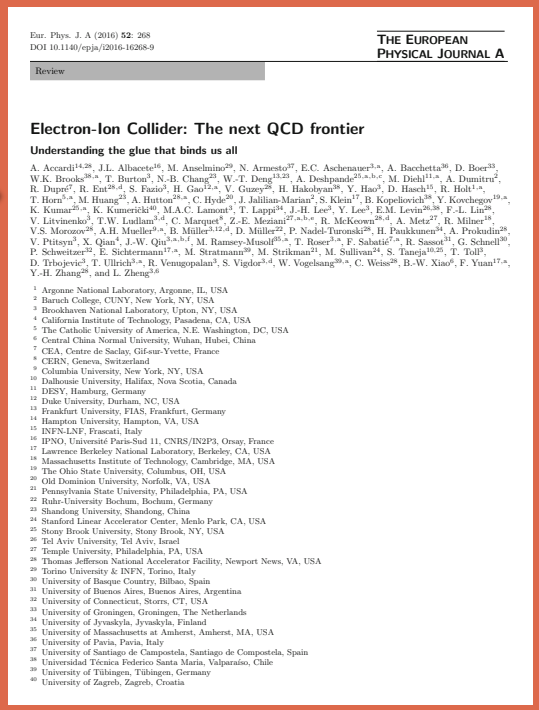
Towards EIC via sPHENIX

An update on the EIC

Stony Brook University

Abhay Deshpande



Eur. Phys. J. A (2016) **52**: 268
DOI 10.1140/epja/i2016-16268-9

THE EUROPEAN PHYSICAL JOURNAL A

Review

Electron-Ion Collider: The next QCD frontier

Understanding the glue that binds us all

A. Accardi[14,28], J.L. Albacete[16], M. Anselmino[29], N. Armesto[37], E.C. Aschenauer[3,a], A. Bacchetta[36], D. Boer[33], W.K. Brooks[38,b], T. Burton[5], N.-B. Chang[23], W.-T. Deng[13,23], A. Deshpande[21,a,b,c], M. Diehl[11,a], A. Dumitru[2], R. Dupré[7], R. Ent[28,d], S. Fazio[3], H. Gao[12,a], V. Guzey[28], H. Hakobyan[38], Y. Hao[3], D. Hasch[15], R. Holt[1,a], T. Horn[5,a], M. Huang[23], A. Hutton[28,a], C. Hyde[20], J. Jalilian-Marian[2], S. Klein[17], B. Kopeliovich[38], Y. Kovchegov[19,a], K. Kumar[21,a], K. Kumericki[40], M.A.C. Lamont[1], T. Lappi[34], J.-H. Lee[3], Y. Lee[3], E.M. Levin[26,38], F.-L. Lin[28], V. Litvinenko[3], T.W. Ludlam[3,d], C. Marquet[8], Z.-E. Meziani[27,a,b,e], R. McKeown[28,d], A. Metz[27], R. Milner[18], V.S. Morozov[28], A.H. Mueller[9,a], B. Müller[3,12,d], D. Müller[22], P. Nadel-Turonski[28], H. Paukkunen[34], A. Prokudin[28], V. Ptitsyn[3], X. Qian[4], J.-W. Qiu[3,a,b,f], M. Ramsey-Musolf[35,a], T. Roser[3,a], F. Sabatié[7,a], R. Sassot[31], G. Schnell[30], P. Schweitzer[22], E. Sichtermann[17,a], M. Stratmann[29], M. Strikman[21], M. Sullivan[24], S. Taneja[10,23], T. Toll[3], D. Trbojevic[3], T. Ullrich[3,a], R. Venugopalan[3], S. Vigdor[3,d], W. Vogelsang[29,a], C. Weiss[28], B.-W. Xiao[6], F. Yuan[17,a], Y.-H. Zhang[28], and L. Zheng[3,6]

[1] Argonne National Laboratory, Argonne, IL, USA
[2] Baruch College, CUNY, New York, NY, USA
[3] Brookhaven National Laboratory, Upton, NY, USA
[4] California Institute of Technology, Pasadena, CA, USA
[5] The Catholic University of America, N.E. Washington, DC, USA
[6] Central China Normal University, Wuhan, Hubei, China
[7] CEA, Centre de Saclay, Gif-sur-Yvette, France
[8] CERN, Geneva, Switzerland
[9] Columbia University, New York, NY, USA
[10] Dalhousie University, Halifax, Nova Scotia, Canada
[11] DESY, Hamburg, Germany
[12] Duke University, Durham, NC, USA
[13] Frankfurt University, FIAS, Frankfurt, Germany
[14] Hampton University, Hampton, VA, USA
[15] INFN-LNF, Frascati, Italy
[16] IPNO, Université Paris-Sud 11, CNRS/IN2P3, Orsay, France
[17] Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[18] Massachusetts Institute of Technology, Cambridge, MA, USA
[19] The Ohio State University, Columbus, OH, USA
[20] Old Dominion University, Norfolk, VA, USA
[21] Pennsylvania State University, Philadelphia, PA, USA
[22] Ruhr-University Bochum, Bochum, Germany
[23] Shandong University, Shandong, China
[24] Stanford Linear Accelerator Center, Menlo Park, CA, USA
[25] Stony Brook University, Stony Brook, NY, USA
[26] Tel Aviv University, Tel Aviv, Israel
[27] Temple University, Philadelphia, PA, USA
[28] Thomas Jefferson National Accelerator Facility, Newport News, VA, USA
[29] Torino University & INFN, Torino, Italy
[30] University of Basque Country, Bilbao, Spain
[31] University of Buenos Aires, Buenos Aires, Argentina
[32] University of Connecticut, Storrs, CT, USA
[33] University of Groningen, Groningen, The Netherlands
[34] University of Jyvaskyla, Jyvaskyla, Finland
[35] University of Massachusetts at Amherst, Amherst, MA, USA
[36] University of Pavia, Pavia, Italy
[37] University of Santiago de Compostela, Santiago de Compostela, Spain
[38] Universidad Técnica Federico Santa María, Valparaíso, Chile
[39] University of Tübingen, Tübingen, Germany
[40] University of Zagreb, Zagreb, Croatia

The EIC Science

Electrion-Ion Collider: The next QCD Frontier

Understanding the glue that binds us all

A.Accardi et al. Eur. Phy. J. A (2016) 52: 268

DOI 10.1140/epja/i2016-16268-9

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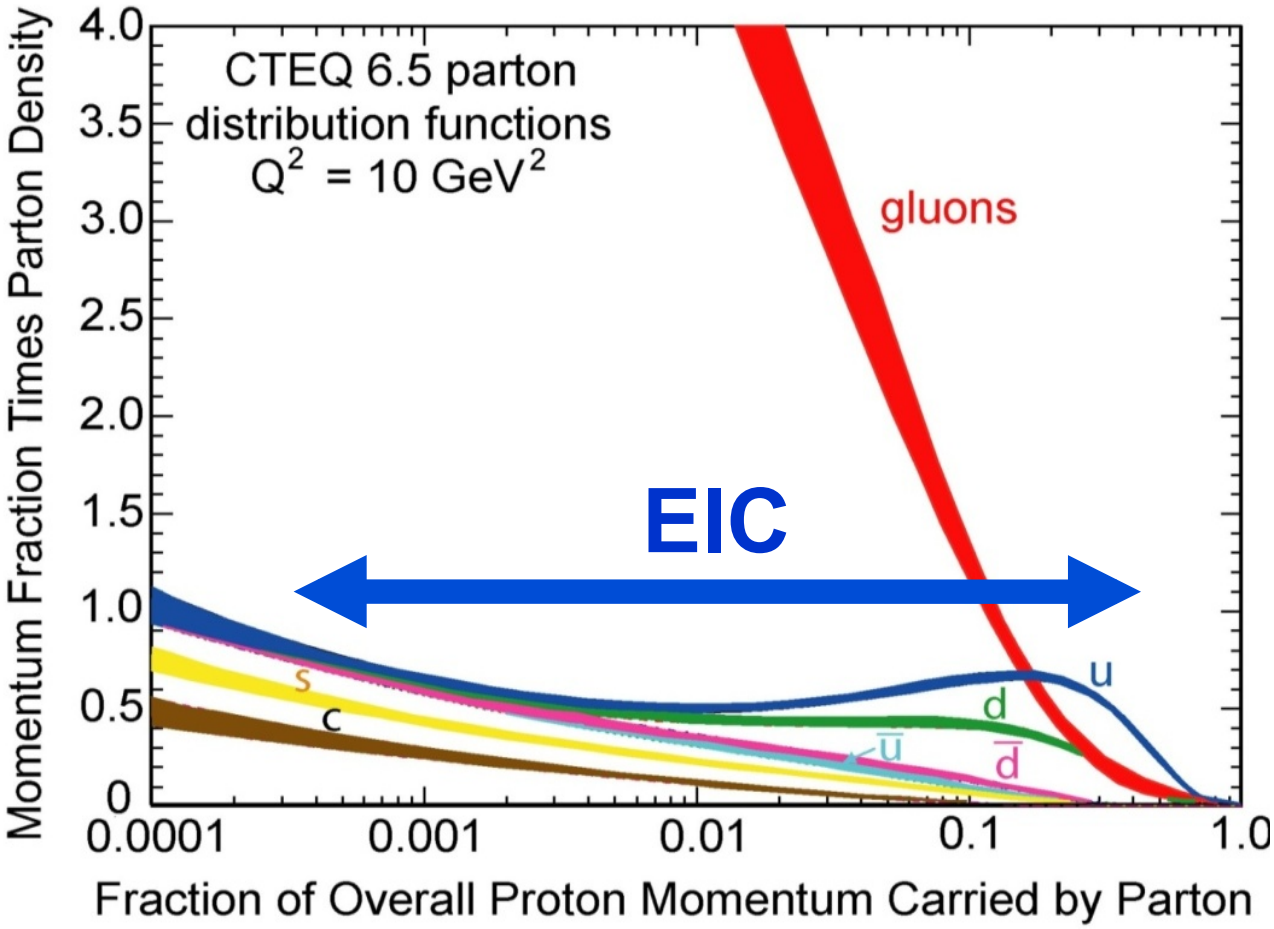
EIC is the "gluon" investigator....



The Electron Ion Collider

Two options of realization!

For e-N collisions at the EIC:

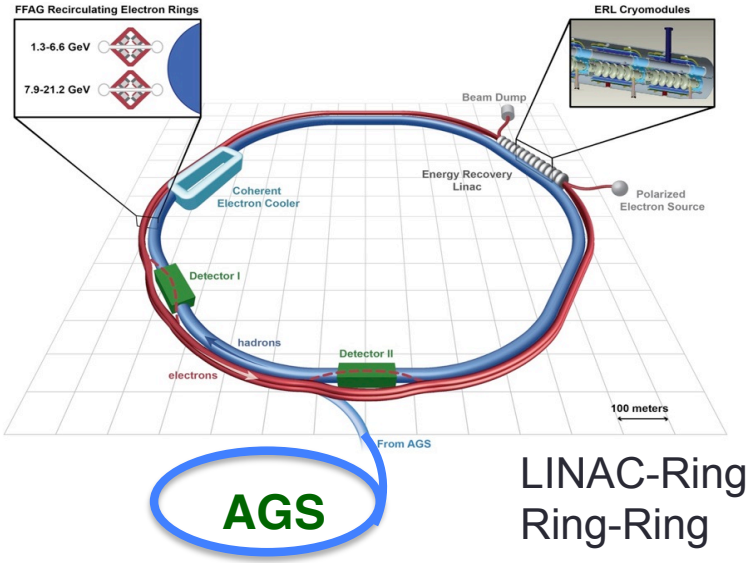
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity $L_{ep} \sim 10^{33\text{-}34}$ cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM

For e-A collisions at the EIC:

- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

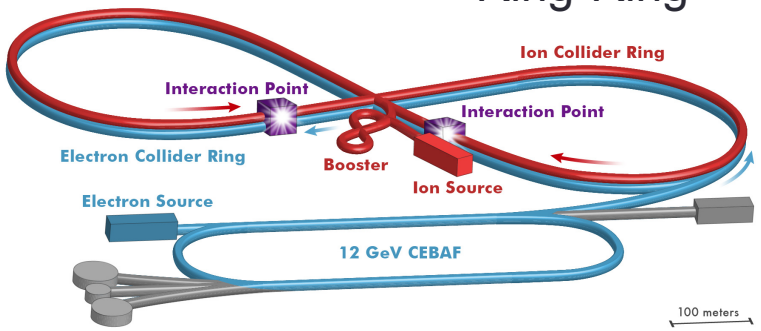
Both designs use DOE's significant investments in infrastructure



LINAC-Ring
Ring-Ring

Not to scale

Ring-Ring



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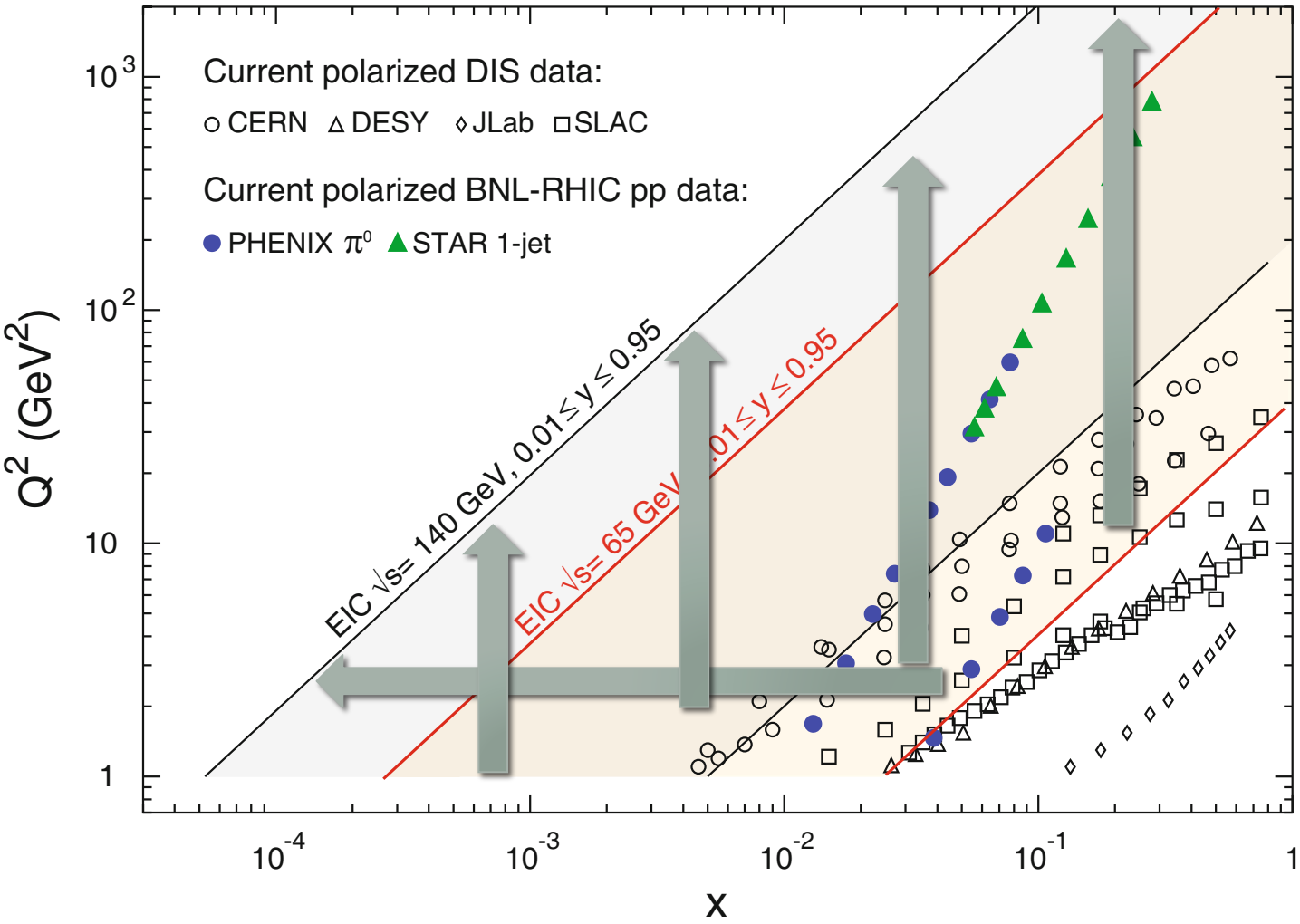
What is new? Polarized e-p :



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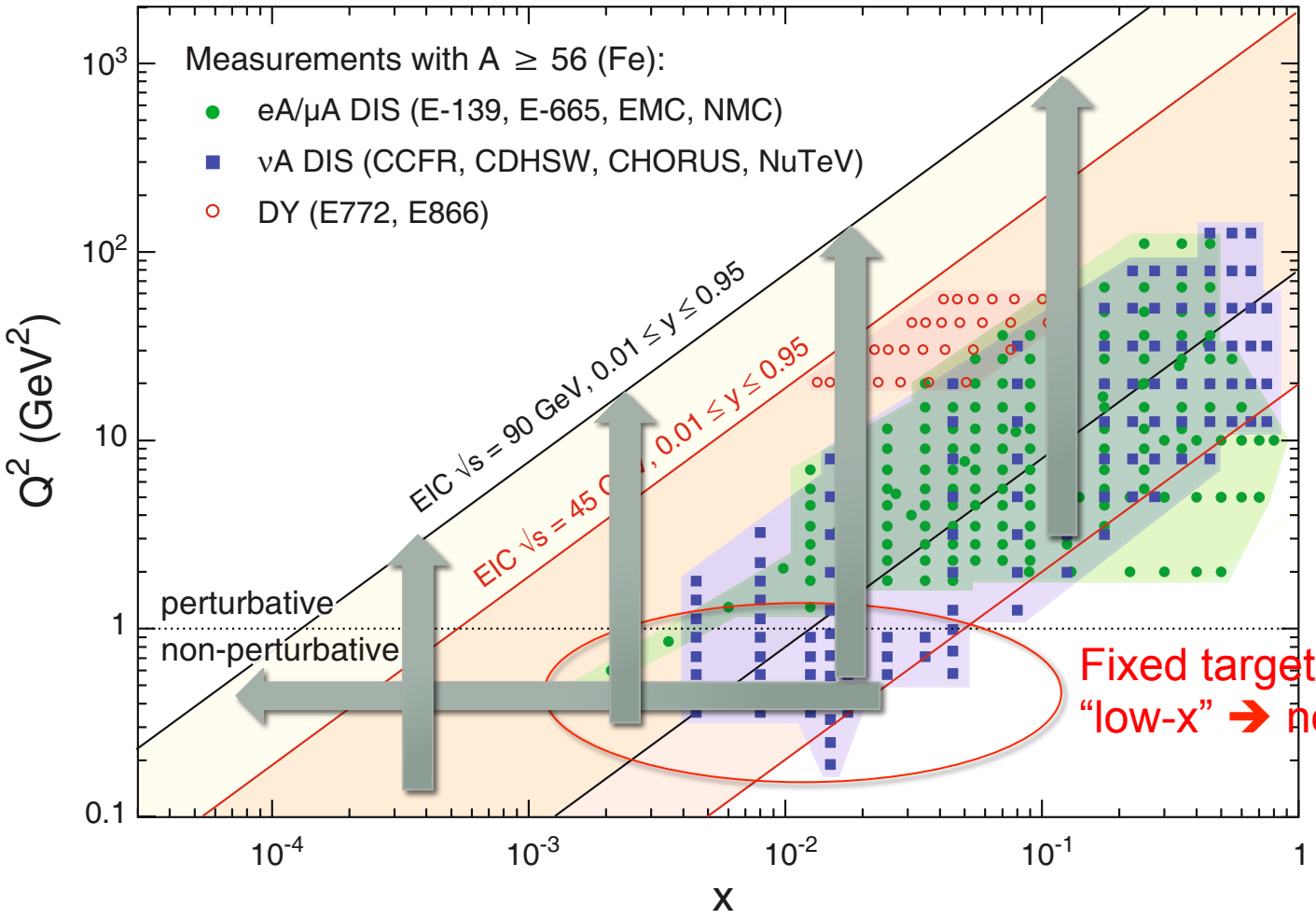
What's new in e-A physics?



Fixed target DIS
"low-x" ➔ non-perturbative

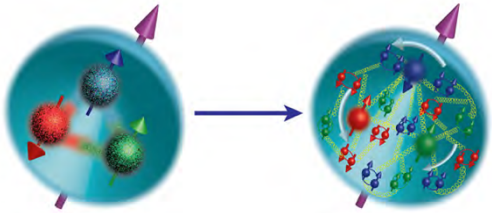
Puzzles and challenges in understanding these QCD many body emergent dynamics

How are the gluons and sea quarks, and their intrinsic spins distributed in space & momentum inside the nucleon?

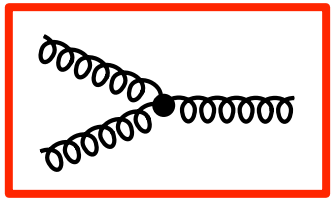
Role of Orbital angular momentum?

How do they constitute the nucleon

Spin?



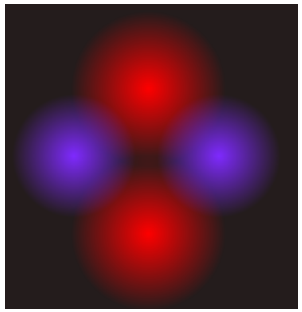
What happens to the gluon density in nuclei at high energy? Does it saturate in to a gluonic form of matter of universal properties?

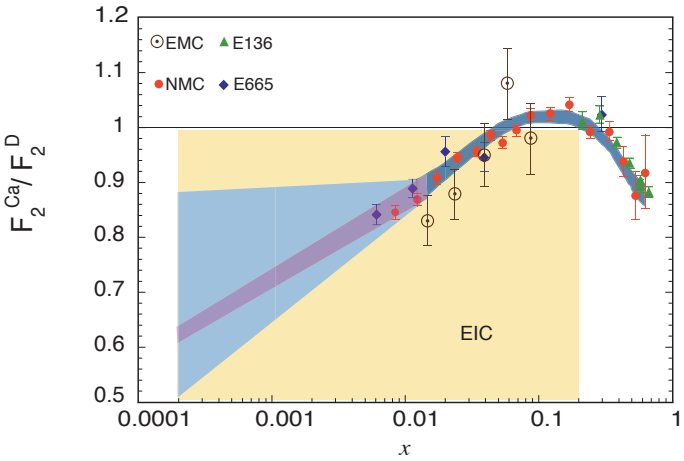


?

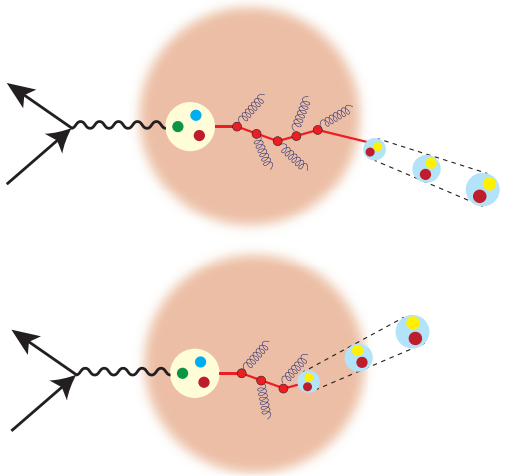
Puzzles and challenges….

How do gluons and sea quarks contribute to the nucleon-nucleon force?





How does the nuclear environment affect the distributions of quarks and gluons and their interactions inside nuclei?



How does nuclear matter respond to fast moving color charge passing through it? (hadronization…. confinment?)

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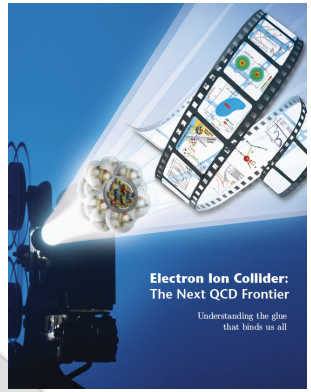
Physics vs. Luminosity & Energy



arXiv: 1212.1701.v3
EPJA 52, 9 (2016)

Luminosity (cm^{-2} sec^{-1})

10^{34}

10^{33}

10^{32}

Electroweak Fundamental Symmetry Tests

Tomography (p/A) Transverse Momentum Distribution and Spatial Imaging

Spin and Flavor Structure of the Nucleon and Nuclei

Parton Distributions in Nuclei

QCD at Extreme Parton Densities - Saturation

86 pb^{-1}/day
1.3 fb^{-1}/month
Assuming 50% efficiency
➔ 6 month operation
➔ 8 fb^{-1}/year

40 80 120

√S (GeV)

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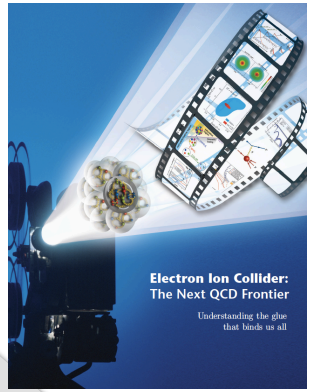
Luminosity conversion and WP Figures

- 10^{33} $cm^{-2}sec^{-1}$ ➔ 86 pb^{-1}
- 30 days a month ➔ 2.58 fb^{-1}/month
- Assume 70% machine and 70% detector efficiency ➔ 50% over all efficieny
- So, 2.58 fb^{-1} /month ➔ 50% ➔ 1.3 fb^{-1}/moth

- Assume 8 months operation per calendar year, 10.4 fb^{-1}/yr

- **All** plots in the EIC White Paper were made with **10 fb^{-1}/yr** integrated luminosity (except for a few).

Time vs. Energy at 10^{33} $cm^{-2}sec^{-1}$



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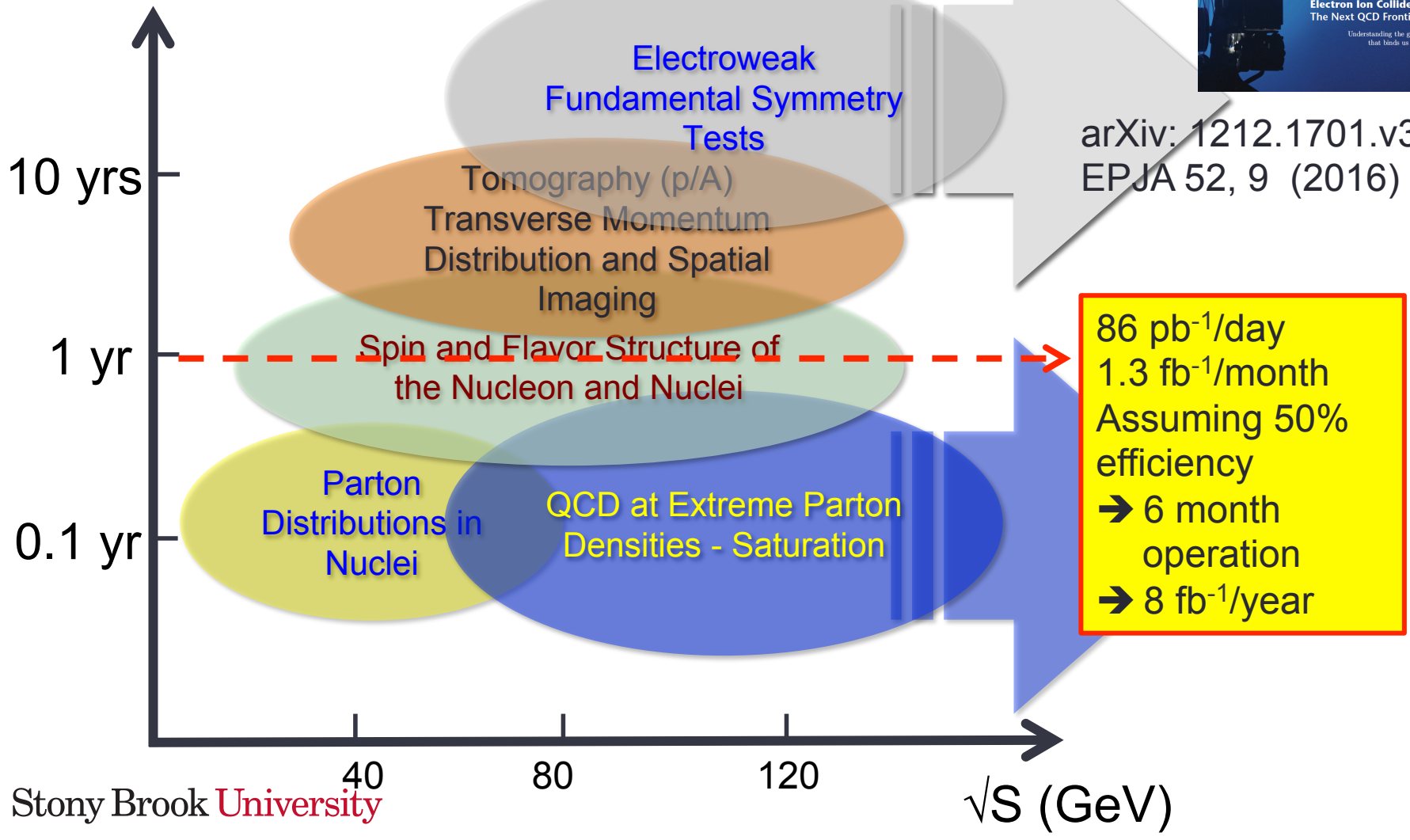

86 pb^{-1}/day
1.3 fb^{-1}/month
Assuming 50% efficiency
➔ 6 month operation
➔ 8 fb^{-1}/year

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eRHIC at BNL

Slides adapted from Bob Tribble's presentation at the INPC 2016 in Adelaide

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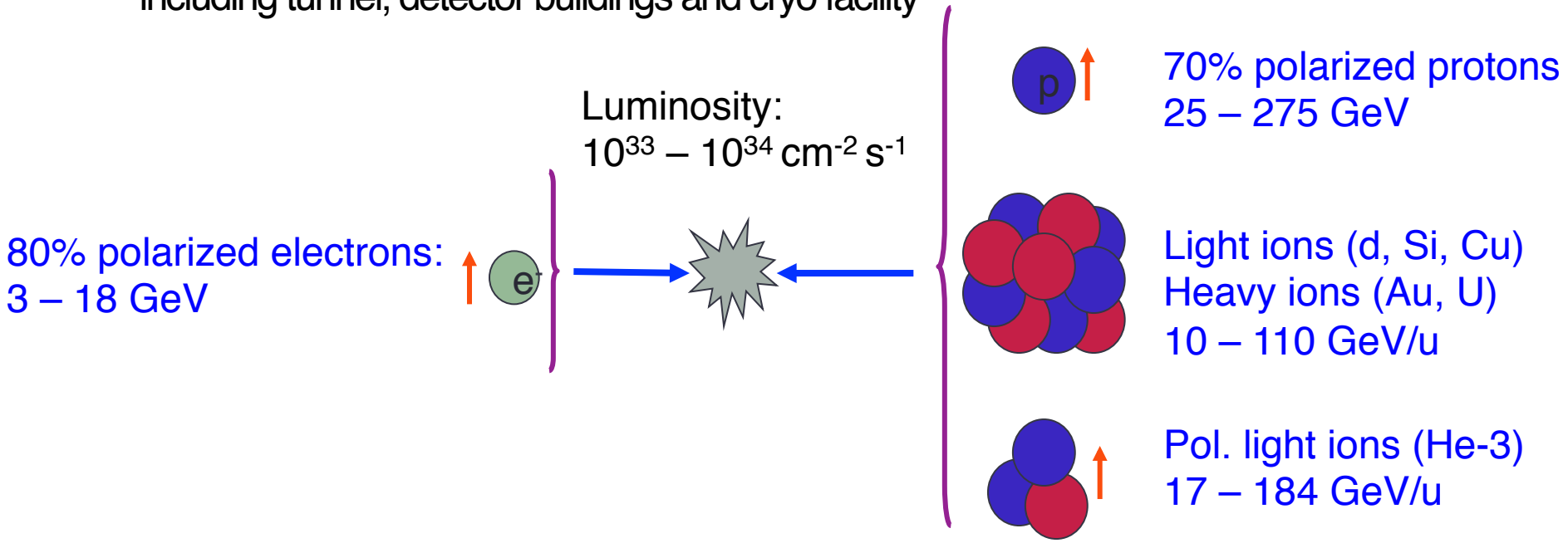
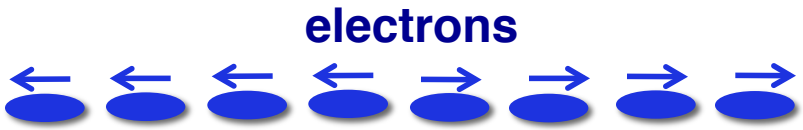
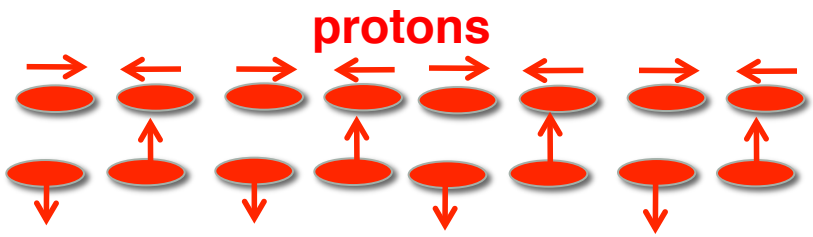
eRHIC: Electron Ion Collider at BNL

Upgrade RHIC by adding an electron accelerator to utilize existing infrastructure, including tunnel, detector buildings and cryo facility



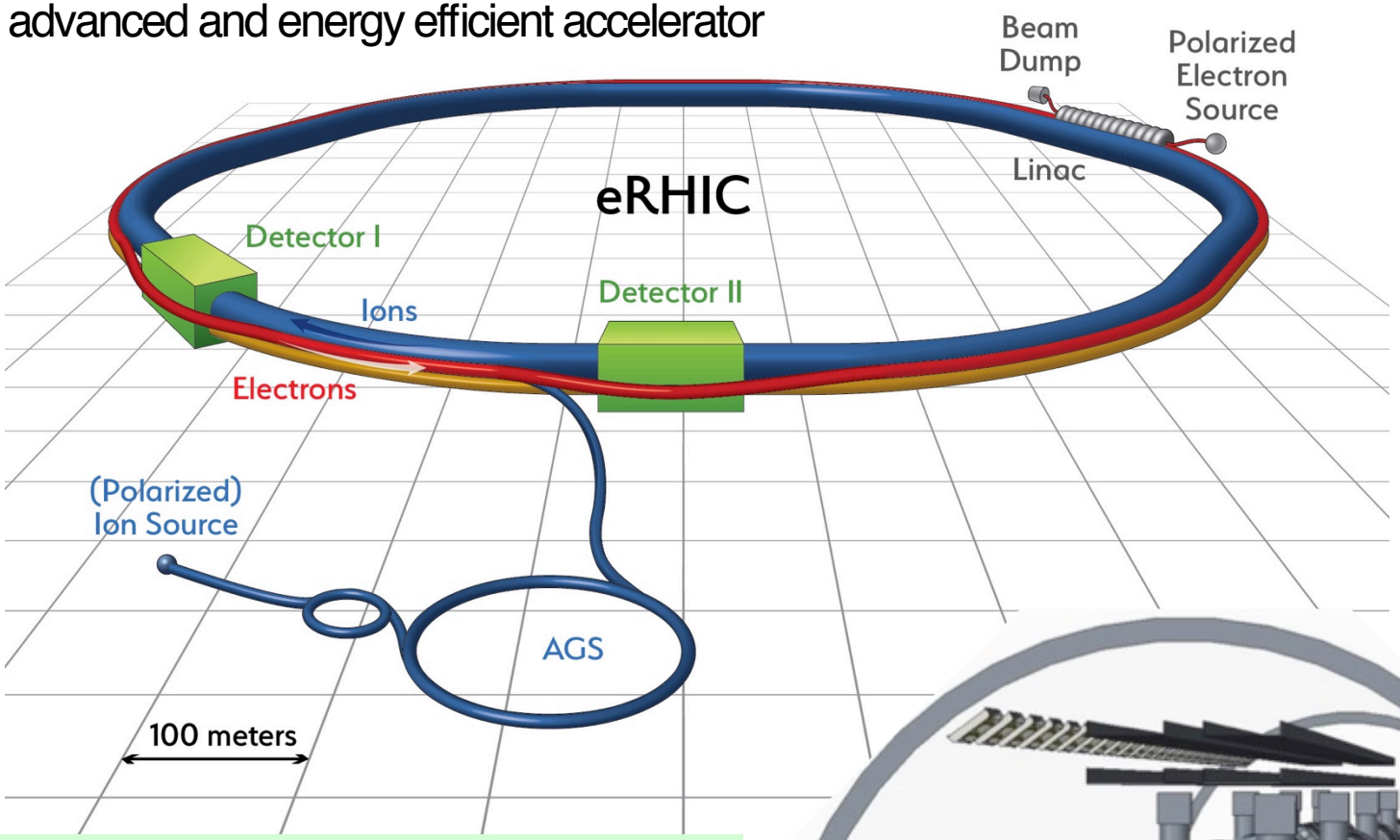
- Center-of-mass energy range: 20 – 140 GeV
- Full electron polarization at all energies
  Full proton and He-3 polarization with six Siberian snakes
- Any polarization direction in electron-hadron collisions:

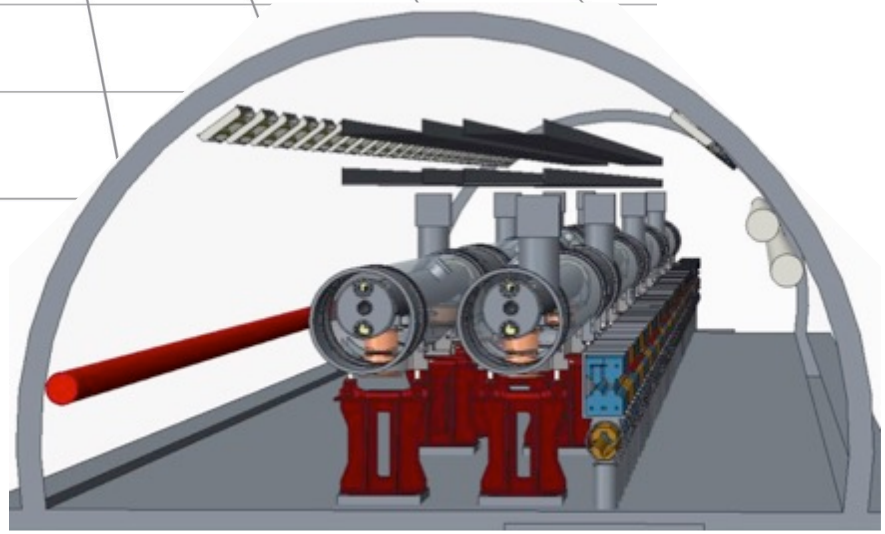




Ultimate eRHIC design

Highly advanced and energy efficient accelerator

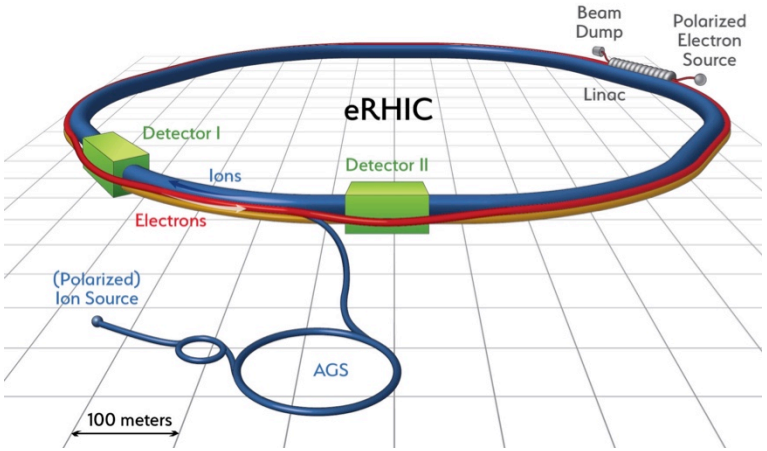




- Peak luminosity: 2×10^{34} cm^{-2} s^{-1}
- ERL and permanent magnet arcs greatly reduce electric power consumption to about 15 MW!

eRHIC design strategy

- **Minimize cost and technical risk:**
  - Center-of-mass energy reach of 140 GeV to cover the whole EIC science case.
  - The initial luminosity will be $10^{32\text{-}33}$ cm^{-2} s^{-1} and will later be increased with the installation of hadron cooling, as was done for RHIC.
- **Low risk ERL-Ring**:
  - Expected to have lower cost, especially if cost reduction R&D is successful
  - Merging beam from eight 6 mA polarized electron guns
  - ERL: 3 GeV, 650 MHz linac with 6 recirculation loops similar to CEBAF
  - High luminosity from colliding bright electron bunches only once with RHIC proton bunches



- **Low risk Ring-Ring**:
  - Based on existing technology.
  - Full energy polarized injector using 6 GeV SRF Linac with 3 recirculation loops
  - High intensity electron storage ring similar to PEP II or KEK-B
  - High luminosity from colliding many intense bunches with RHIC proton bunches
- With fast e-cooling both designs upgraded to the ultimate eRHIC ERL-Ring machine

eRHIC R&D (new director: F. Willeke)

Four high priority eRHIC R&D items to be completed in 2 – 3 years for cost reduction and performance upgrade:

- **High intensity polarized electron source**
  - Efforts at BNL/SBU (Gatling gun) and MIT (Large cathode gun)
- **ERL acceleration cavity with full Higher Order Modes (HOM) damping using waveguide dampers**
  - LDRD funded effort to reduce ERL linac cost with higher Q cavities and more compact HOM designs
- **Coherent electron Cooling Proof-of-Principle test at RHIC**
  - Competitive NP R&D funding; R&D for EIC luminosity upgrade
- **High intensity, multi-pass test-ERL with single recirculation loop (FFAG) to be built using the Cornell high intensity electron injector and CW SRF Linac (C-Beta)**
  - NYSERDA funded project to construct an eRHIC prototype. FFAG demonstration would greatly reduce cost of eRHIC.
- ~ $200 – 300M of possible EIC project cost savings from this R&D

The EIC User Group and RHIC/Jlab Users & Interests

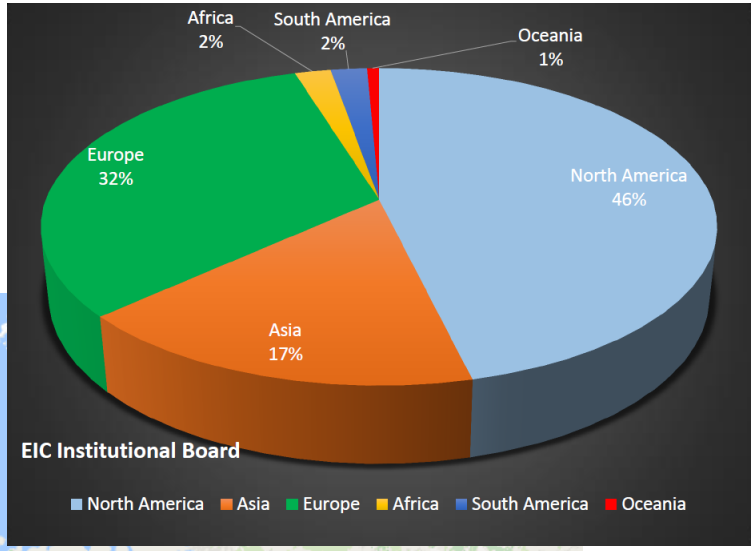
The EIC Users Group: EICUG.ORG

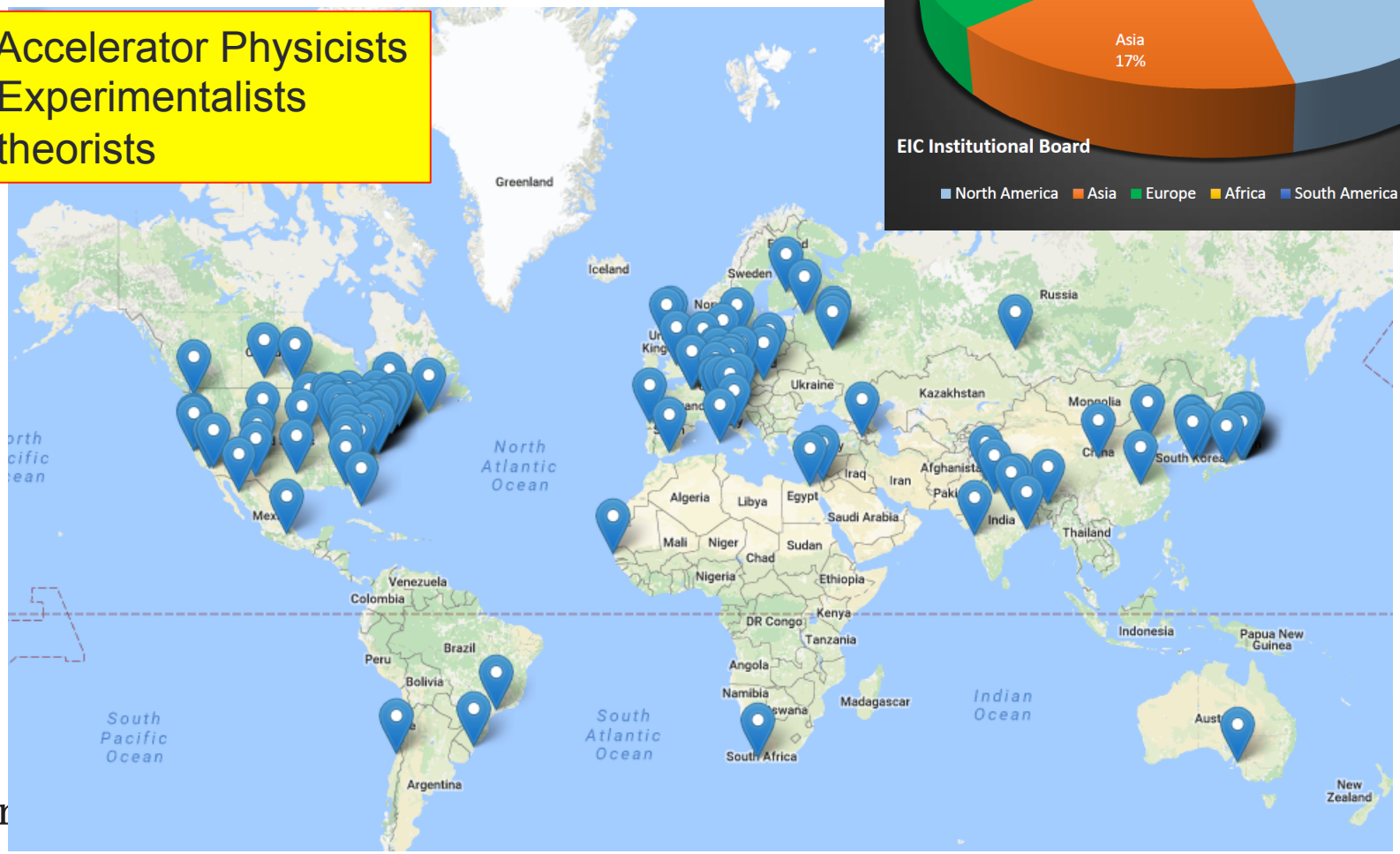
(no students included as of yet)

663 collaborators, 28 countries, 147 institutions... (October 09, 2016)

Map of institution's locations

~141 Accelerator Physicists
~391 Experimentalists
~131 theorists





News from the Users Group: Organization

- **Institutional Board (IB)** held its elections: Christine Aidala was elected Chair of the IB

- **Elected Steering Committee & its Chair (Spokesperson):**
  - Christine Aidala (ex-officio: IB Chair)
  - John Arrington (ANL)
  - Abhay Deshpande (SBU, Chair SC & Spokesperson)
  - Charles Hyde (ODU)
  - Marco Radici (INFN)
  - Bernd Surrow (Temple, Deputy Chair)
  - + 2 more regional members expected to join (Europe & Asia)

- **Nominated Members from BNL and Jlab**
  - Elke Aschenauer (BNL)
  - Rik Yoshida (Jefferson Lab)

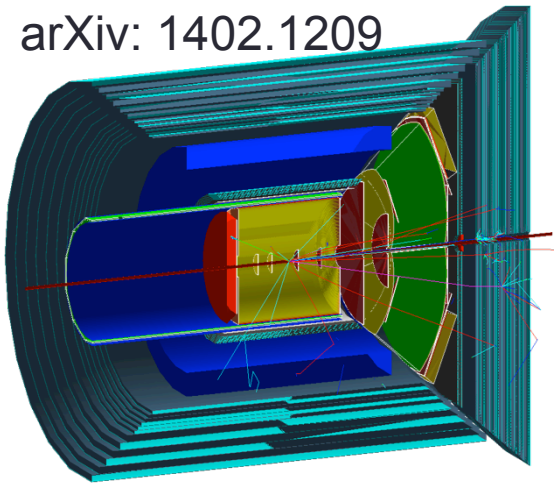
First meeting of SC 12/22/2016

EICUG & Detector Considerations

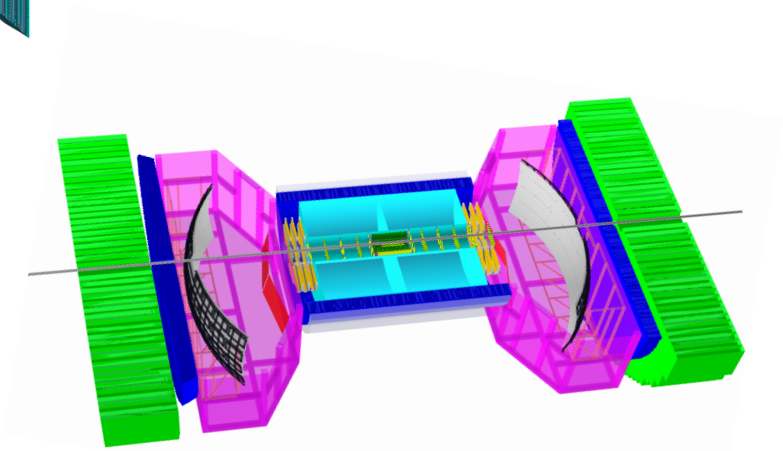
Many ePHENIX related issues already discussed in the talk by Christine Aidala and Nils Feege

Emphsize: we should plan for two detectors for eRHIC with potentially 2000 users getting involved….

Day-1 Detector: CELESTE(?)
A.K.A. “ePHENIX” with BaBar Solenoid
arXiv: 1402.1209



ePHENIX ➔ solidifying as an idea of a Day 1 Detector -- Need to revisit study some key measurements again
>> DVCS, diffraction, exclusive DIS with spin
>> IR Design with roman pots
These studies now initiated.

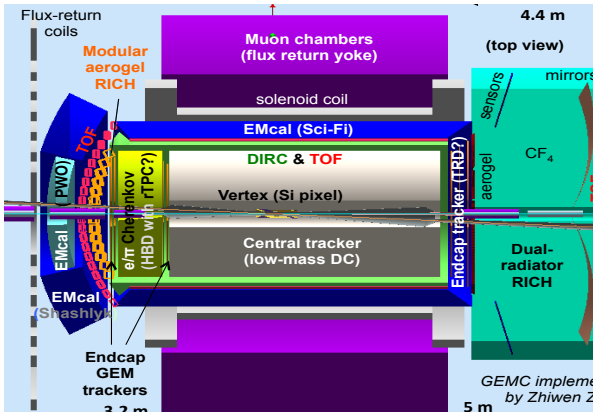


BEAST by BNL’s EIC Task Force arXiv: 1409.1633

Two Green Field detectors

NOT TO SCALE

JLEIC Working Group



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Progress and updates

- **Cold-QCD Working Group** formed, activities began:
  - Christine Aidala and Nils Feege (conveners)
  - Expect science contributions and discussions to evolve
  - Vasily Jorjadje (now Stony Brook adjunct) already pursuing detailed simulations of DVCS physics with most updated sPHENIX/ ePHENIX detector/GEANT simulations, will involve more SBU UG students in the near future.

- One critical item: **eRHIC IR Design and ePHENIX**
  - With Pawel Nadel-Turonski (now Stony Brook Adjunct) recently initiated discussion of ePHENIX and eRHIC IR design
  - Plan to work with the machine designers and IR design folks from Jlab and RHIC (Brett Parker & Robert Palmer) on the ePHENIX IR issues essential to be sorted out in short time scale.

Tim Hallman's presentation at NSAC March 2016

Next Formal Step on the EIC Science Case

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE
Division on Engineering and Physical Science
Board on Physics and Astronomy
U.S.-Based Electron Ion Collider Science Assessment

Summary

The National Academies of Sciences, Engineering, and Medicine ("National Academies") will form a committee to carry out a thorough, independent assessment of the scientific justification for a U.S. domestic electron ion collider facility. In preparing its report, the committee will address the role that such a facility would play in the future of nuclear science, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics. The need for such an accelerator will be addressed in the context of international efforts in this area. Support for the 18-month project in the amount of $540,000 is requested from the Department of Energy.

Mail reviews received; proposal approved for funding in PAMS; PR package in PAMS being processed.

Progress is also being made on a second Joint NAS study on Space Radiation Effects Testing

National Academy's Review of EIC

- Review committee:
  - *A. Aprahamian (Notre Dame, Co-Chair)*
  - *G. Baym (UIUC, Co-Chair)*
  - *C. Aidala (U. Michigan)*
  - *R. Milner (MIT)*
  - *Z.-E. Meziani (Temple)*
  - *T. Schaefer (NC State)*
  - *M. Turner (U. of Chicago)*
  - *W. Haxton (UC Berkeley)*
  - *K. Hafidi (ANL)*
  - *P. Braun-Munzinger (GSI)*
    H. Gao (Duke)
  - *J. Jowett (CERN)*

First organizational meeting:
Early February 2017

Then 3-4 meetings every month

Report expected end of 2017

The EICUG has been working since October on preparing the presentations for the NAS review.

Anticipate invitations to present after the organizational meeting i In early Ferbruary

EICUG's Role in NAS Review

- Currently a small group of EICUG working on the four questions that constitute the Charge given to the National Academy. Aim to produce a set crisp set of answers for who ever will be asked to present the case.
  - Expect to be ready by late December early January
  - First NAS review meeting in February 2017
  - Science presentations March 2017

- During the EIC NAS review there will be opportunities for input from the EIC UG members.
  - EICUG and its management will plan input from key members including international to impress upon the NAS committee, of their high interest.

Tim Hallman at NSAC March 2016

Seeding the Possibility of a Future Electron Ion Collider

NP Planning for EIC Accelerator R&D

In view of Recommendation III in the 2015 LRP report on the realization of an EIC, NP is fomenting a plan in discussion with EIC stakeholders:

18 months NAS study:	US-BASED ELECTRON ION COLLIDER SCIENCE ASSESSMENT
March - July 2016:	Competitive FOA published this month, proposals due May 2 to select and fund accelerator R&D for Next Generation NP Facilities for 1 year only.
Summer 2016	Conduct an NP community EIC R&D panel (EIC-R&D) Review charged with generating a report as basis for FY17-FY20+ EIC accelerator R&D funding. NP to appoint Chair of the panel
Late Fall 2016:	Use the EIC panel report from the panel to publish a new Accelerator R&D FOA for FY2017 funding.

Funding amount and source for EIC accelerator R&D in FY17 and beyond:

Funding level:	Aiming for $7M, exact amount to be guided by EIC-R&D Review's report
Funding sources:	~$1.9M from NP competitive pot, the rest generated by percentage tax to RHIC and CEBAF Accelerator Operations budgets (~2.6% FY17 president request for each Lab).

Tim Hallman at NSAC March 2016

R&D for a Possible Future Electron Ion Collider

EIC R&D Panel Review:

Panel Formation: A community panel, similar to Ozaki panel for RIA.

Charge to Panel: Panel to generate a list of EIC accelerator R&D items with relative priority and estimated cost and duration ranges.

EIC design Concepts: examine current EIC concepts under considerations in the US and identify a risk level (high, medium or low) for realization of each concept,

Technical Feasibility: For each EIC design concept, identify key areas of accelerator technologies that must be demonstrated or advanced significantly in order to realize the technical feasibility of the concept.

Status of EIC R&D to date: Evaluate current state of EIC related accelerator R&D supported by NP competitive R&D funds and by individual NP Labs.

Priority list of R&D: Generate a list of R&D areas for each EIC concept, prioritized (High, Medium, Low) in the context of associated risk and impact of value engineering and technical feasibility.

Cost and Schedule range: Provide an estimate of cost and schedule range associated with each R&D item from the list of R&D above.

First meeting Nov. 29-Dec.2

EIC Generic Detector R&D

November 22, 2016 DOE visit to ask for doubling (trippling the funds) ➔ about $4M/yr from the current $1.3M

Visit by Abhay Deshapnde, Marcel Demarteau &Thomas Ullrich

T. Ullrich

Generic Detector R&D for an EIC

- Funded by DOE, managed by BNL: 1M$-1.5M$/year
- Program explicitly open to international participation
- Key to success: Standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology and collider physics
  - Meets twice a year, funding limited to one year (FY)
    - ~January: Review of ongoing projects
    - ~July: Review and new proposals*







Current: Marcel Demarteau** (ANL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick Van Berg (UPenn), Jerry Va'vra (SLAC), Glenn Young (JLab)

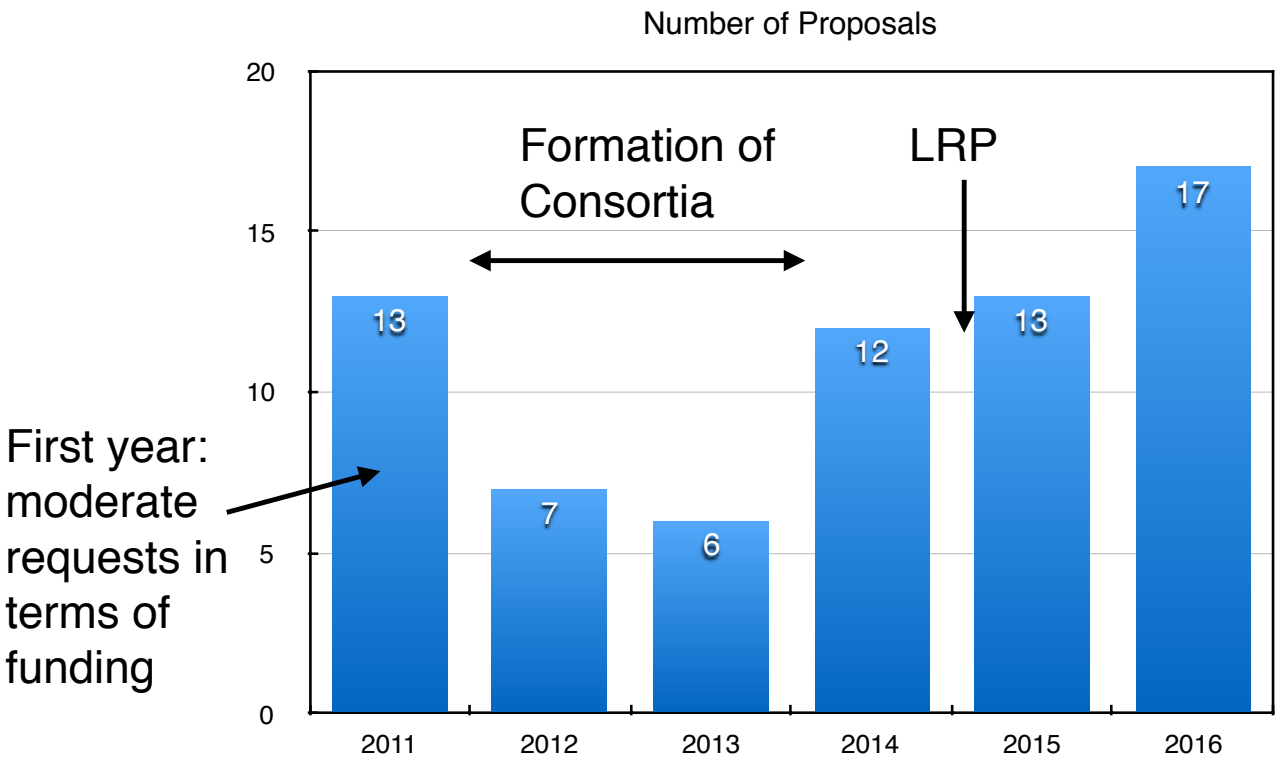
**Chair


Retired:
Robert Klanner (Hamburg), Howard Wieman (LBL)

* During 2011-2014 new proposals were also accepted in the Winter meeting

Statistics (I)

T. Ullrich

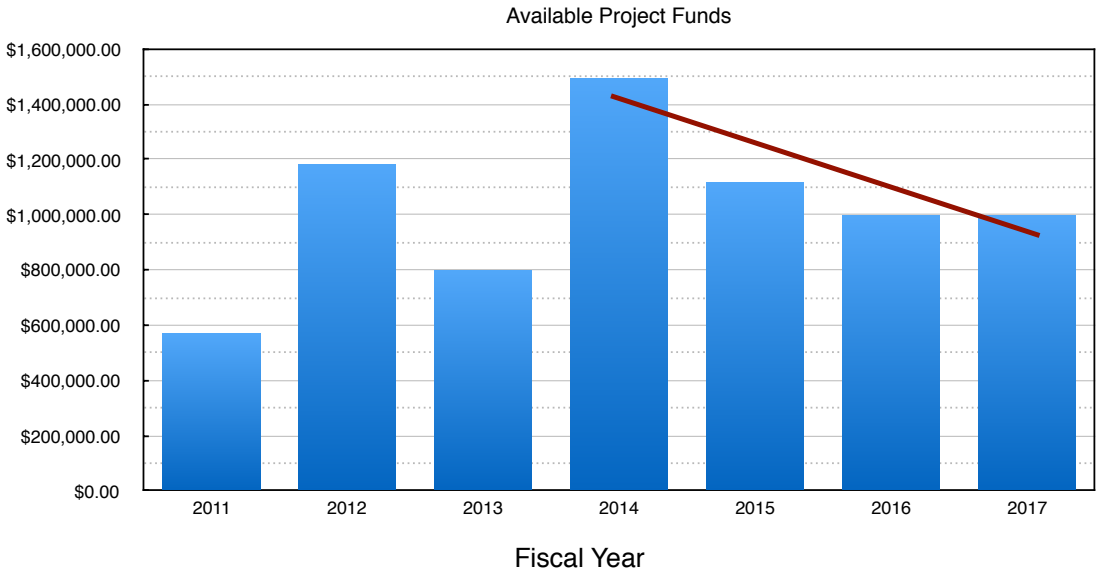


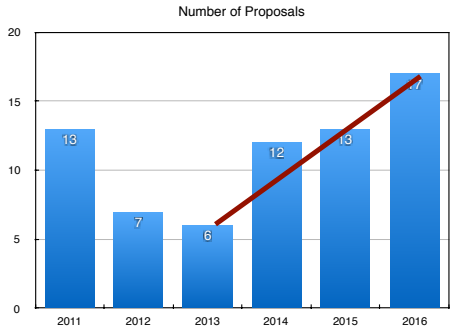
Note: < 2014 proposals were considered every 1/2 year. Those are added up.

- FY17: Record participation this time (expected)
  - 8 new proposals, new strong international groups

Statistics (II)

T. Ullrich



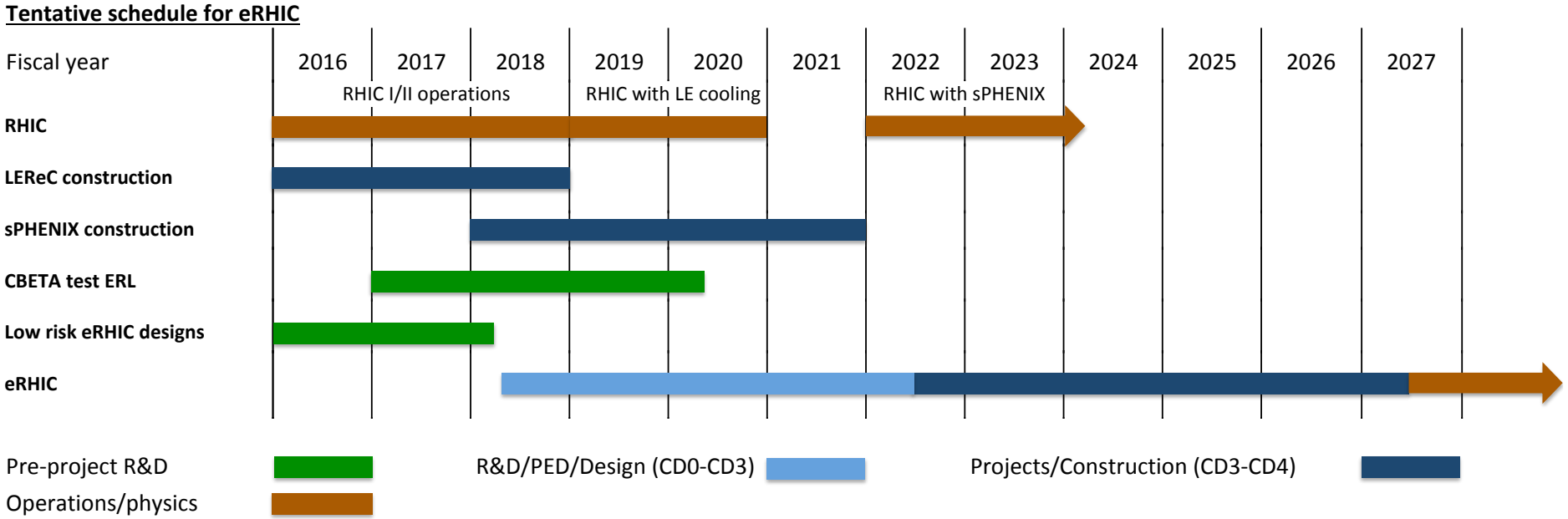


WE ASKED FOR
$1.3M → $4M/yr
Over the next 2-yrs

- Funding
  - Total since 2011: $7,721,740
  - Total funds requested for FY17: $2.45M: worst ratio of available/requested funds ~ 0.41
- Participation (present)
  - 48 institutions (11 non US)
  - ~140 participants

Stony Brook University

Tentative schedule for RHIC and eRHIC (R. Tribble)



- 2017/18: two more RHIC Runs 17 and 18 with eLens and 56 MHz
- Low Energy RHIC electron Cooling (installation in 2018) for RHIC Runs 19 and 20 (Beam Energy Scan II)
- sPHENIX construction (final installation during 2021) for two RHIC Runs 22 and 23
- Low risk design (pCDR) complete by 2018
- High priority eRHIC R&D items complete by 2019
- eRHIC: mission need (CD-0 in 2018?), alternative selection (CD-1 in 2019?), project baseline (CD-2 in 2020?), construction start (CD-3 in 2022?), installation (2024 – 2026?) and start of operation (CD-4 in 2027?)

Summary….

Since Long Range Plan blessed the EIC in October 2015, movement towards its realization has begun on many fronts

- EIC Users Group (an umbrella collaboration beyond RHIC, JLab and International facilities Users) formed, and is getting organized
- National Academy's Review is now underway and expected to give their verdict in about a year from now
- EIC Accelerator R&D for cost reduction initiated towards enabling a site selection in 2019
- Great to see sPHENIX → ePHENIX organized effort has also begun

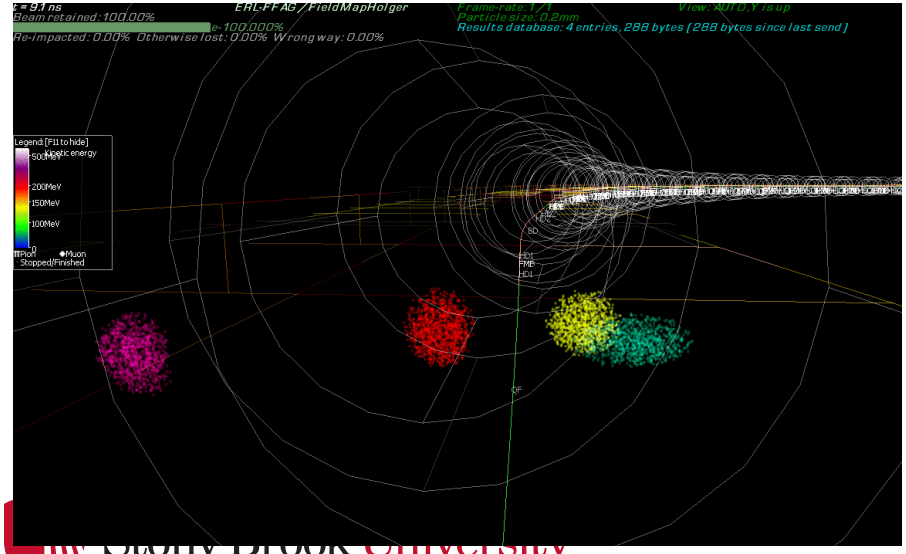
Backups

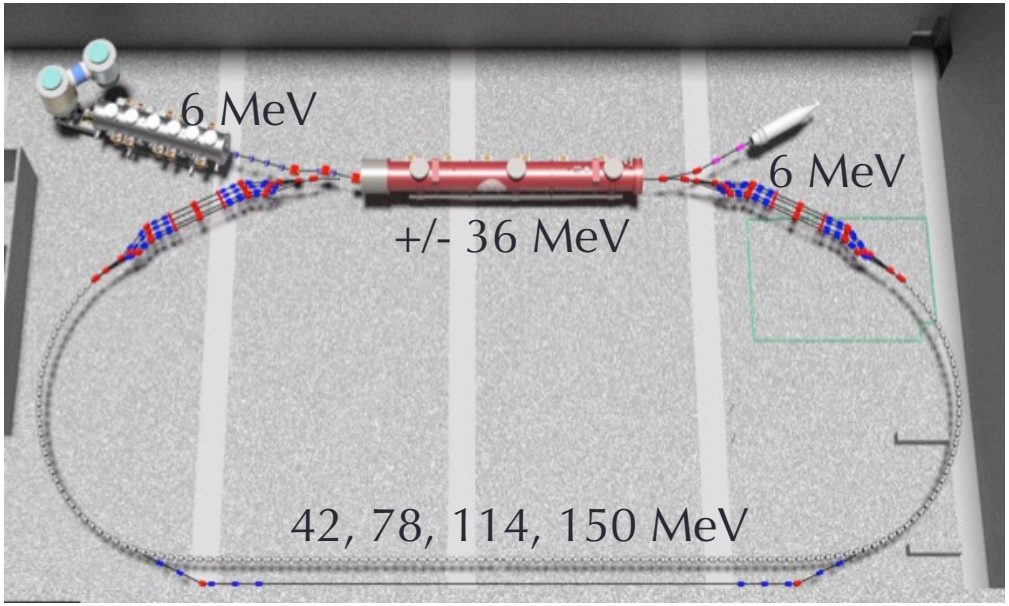
Coherent electron Cooling (CeC)

- DOE NP R&D project aiming for demonstration of CeC technique is in progress since 2012
- Phase I of the equipment and most of infrastructure installed into RHIC's IP2
- First beam from SRF gun (3 nC/bunch, 1.7 MeV) on 6/24/2015; exceeds performance of all operating CW electron guns
- 20 MeV SRF linac and helical wigglers for FEL amplifier are installed, 8 MeV beam transported to beam dump
- Proof-of-principle demonstration with 40 GeV/n Au beam scheduled during RHIC Run 17
- Micro-bunching test also planned with same set-up

C-Beta test-ERL at Cornell – an eRHIC prototype

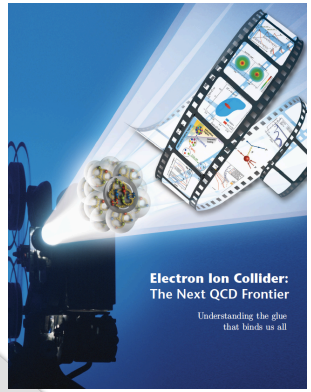
- Uses existing 6 MeV high-current injector and 36 MeV CW SRF Linac
- ERL with single four-pass recirculation arc with x4 momentum range
- Permanent magnets used for recirculation arc
- Adiabatic transitions from curved to straight sections
- Test of spreader/combiner beam lines
- Beam test of eRHIC cavities and cryostats possible
- NY State funding awaits September NYSERDA board meeting
- Cost/schedule review (“CD2/3”) in October 2016

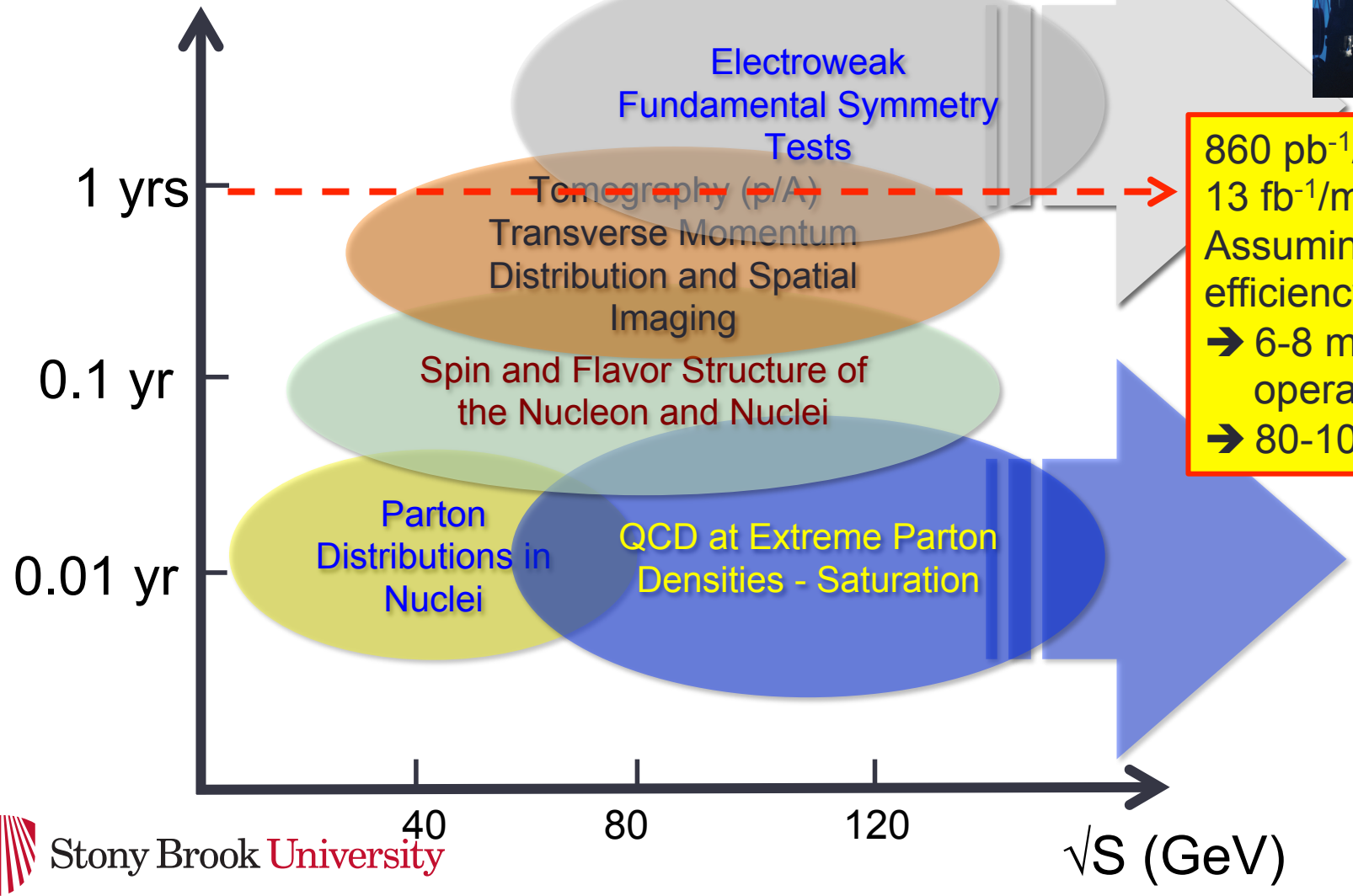




Time vs. Energy at 10^{34} $cm^{-2}sec^{-1}$

arXiv: 1212.1701.v3
EPJA 52, 9 (2016)





860 pb^{-1}/day
13 fb^{-1}/month
Assuming 50% efficiency
➔ 6-8 month operation
➔ 80-104 fb^{-1}/year

Stony Brook University